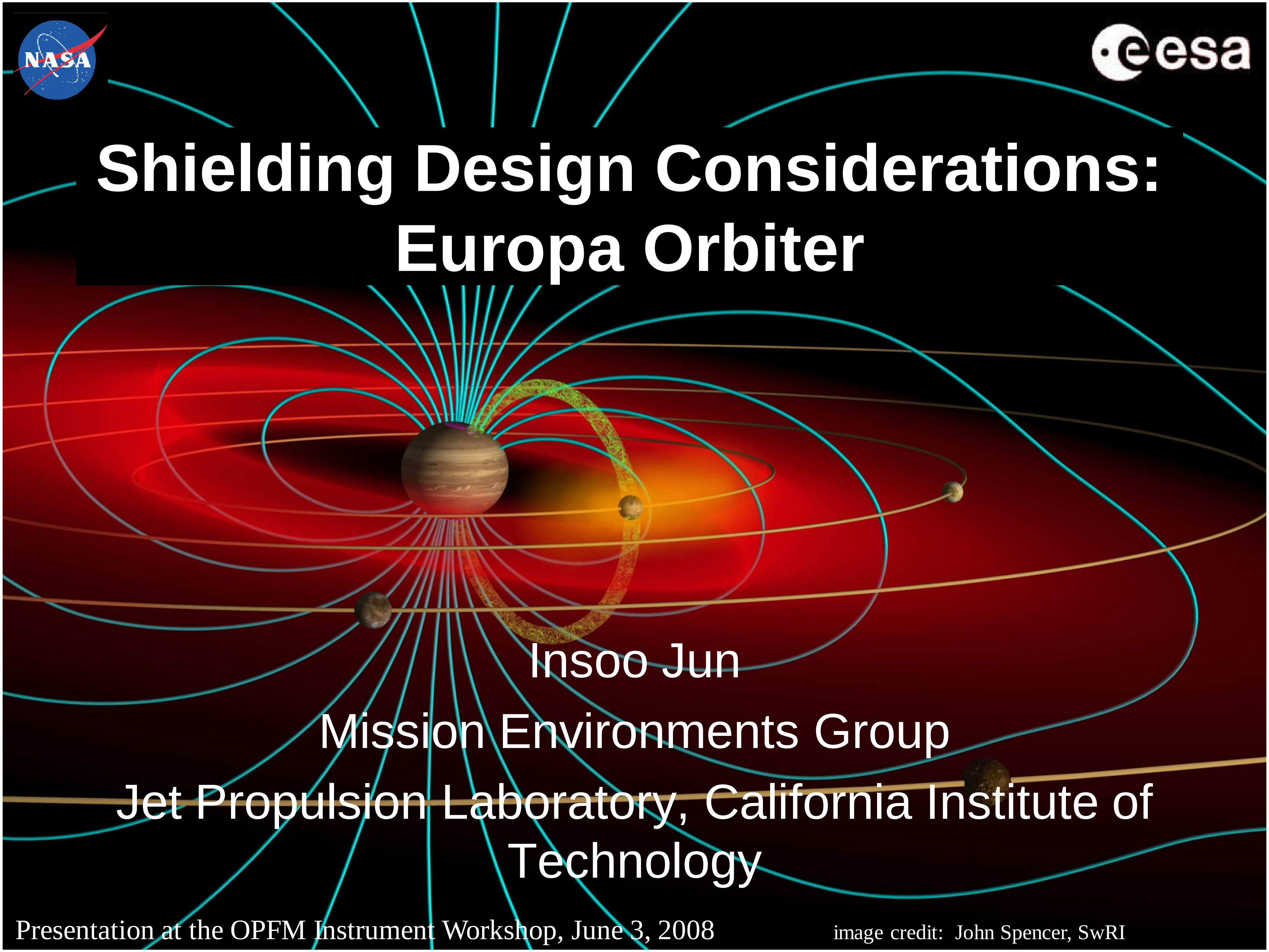
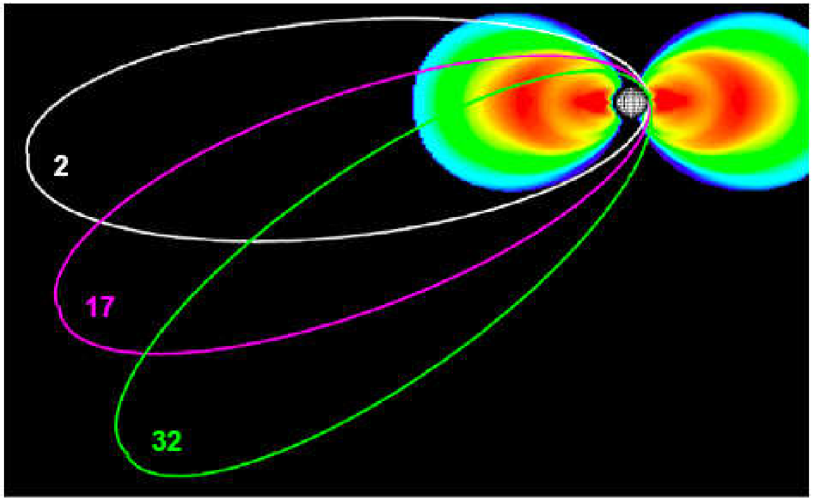

NASA
esa
Shielding Design Considerations:
Europa Orbiter
Insoo Jun
Mission Environments Group
Jet Propulsion Laboratory, California Institute of Technology
Presentation at the OPFM Instrument Workshop, June 3, 2008
image credit: John Spencer, SwRI

Principles of Radiation Protection

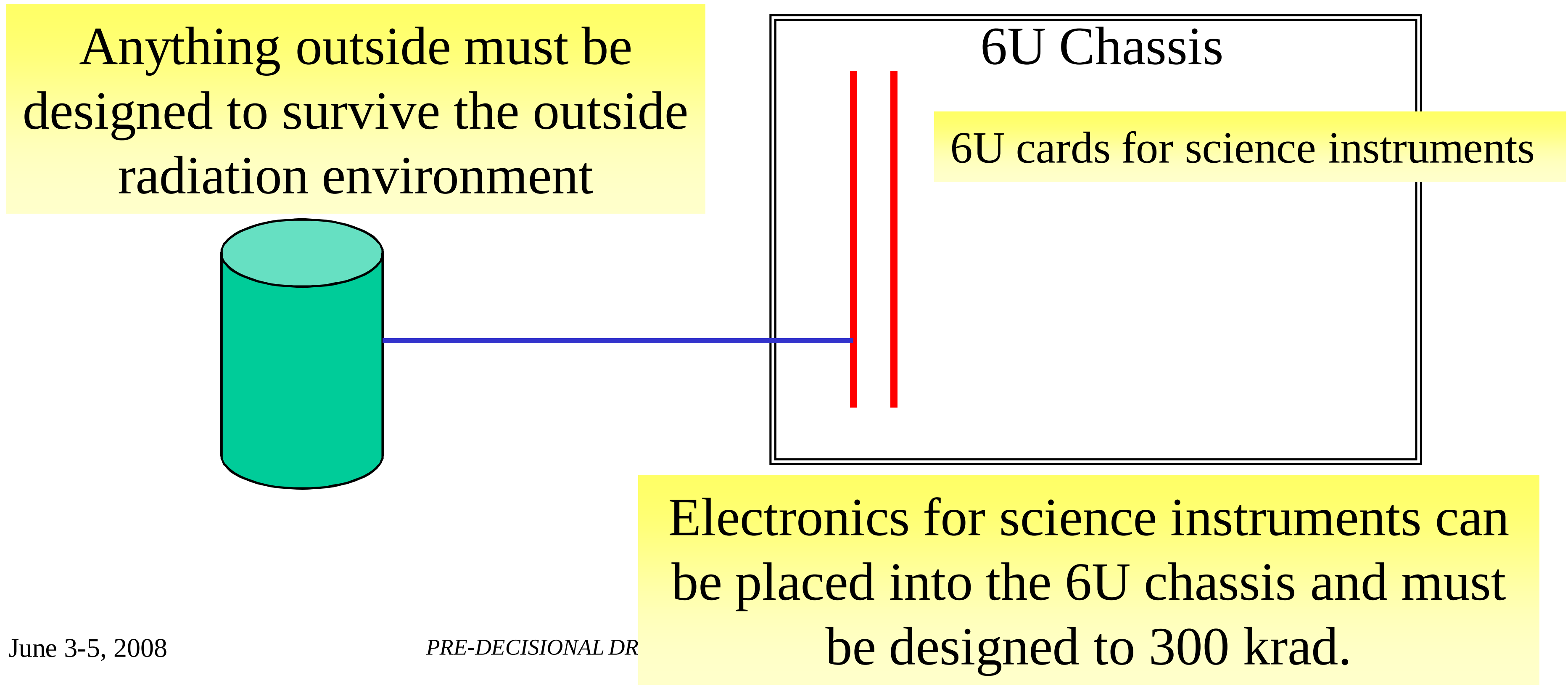
- Minimize the Time of Exposure
  - Careful selection of trajectory, e.g., Juno.
  - Europa Orbiter also stays out of the intense radiation belt in the early phase of jovian tour.
- Maximize the Distance from the Source
  - Place flight electronics and science instruments away from MMRTG.
  - Not possible in the space radiation environment.
- Design Radiation Hardened Parts or Sensors
  - Cost
- Use Shielding



Perijove Passage through Jupiter's Radiation Environment

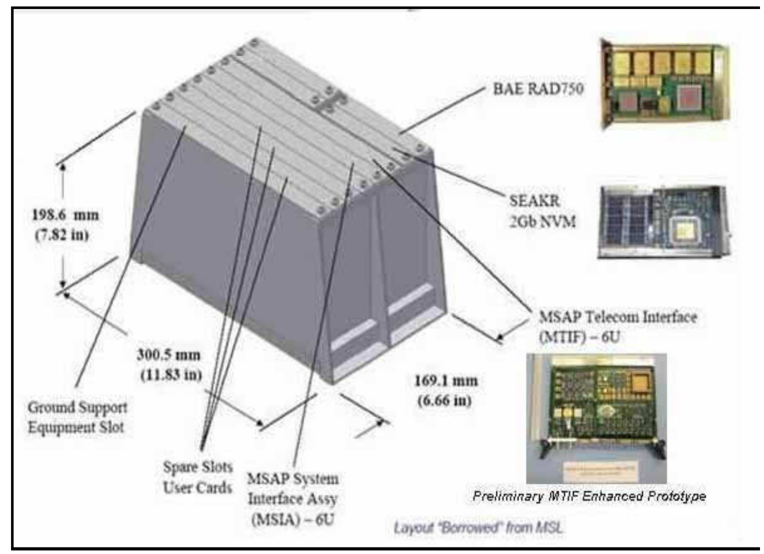
EO Radiation Shielding Design Guideline

- Electronics/instruments/materials must meet the RDF=2 requirement.
  - For example, if there are 300 krad parts used in the electronics, the shield should brings the dose down to 150 krad.
  - The RDF=2 requirement also applies to displacement damage dose.



Shielding Approach for Electronics

- Distribute shielding
  - Accommodates widely different part tolerance levels among subsystems (0.1 to 1 Mrad)
  - Minimizes mass by avoiding the overhead of shielding everything to the "lowest common denominator"
- Use standard 6U shielded chasses for all electronics packaged on cards
- Use shielded enclosures for pre-packaged electronics or sensors/detectors

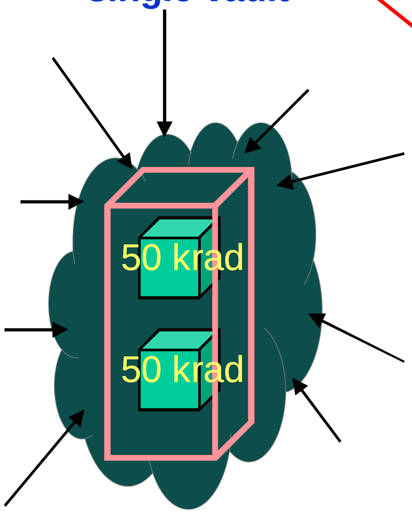


6U Cards Shielded Chassis

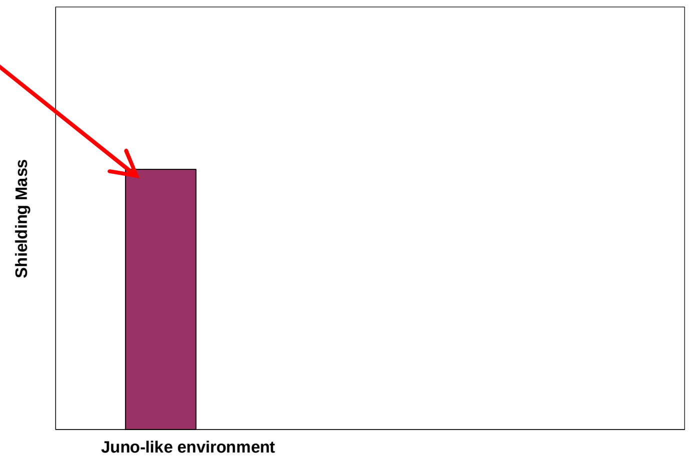
Shield Mass Comparison - A Simple Case Study

Scenario: Examine the trend of shielding mass changes for 2 electronics boxes in a Juno-like radiation environment vs. a Europa-like environment

Juno-like environment and single vault



Shielding for RDF=2

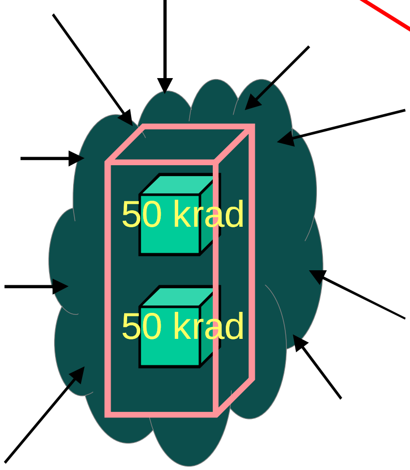


Shield Mass Comparison - A Simple Case Study

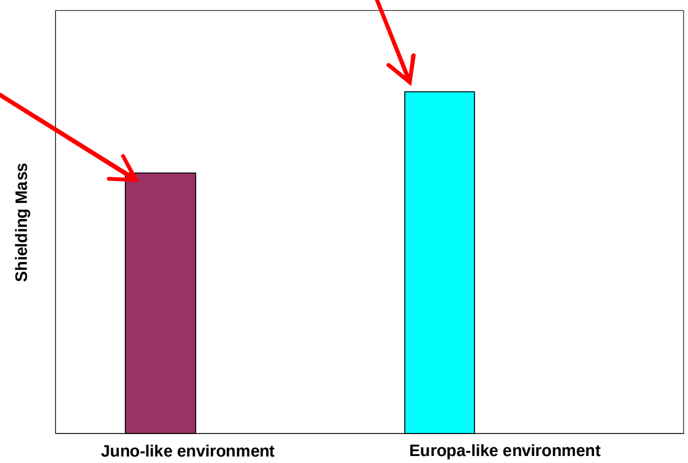
Scenario: Examine the trend of shielding mass changes for 2 electronics boxes in a Juno-like radiation environment vs. a EO-like environment

Two boxes in a single vault in Juno-like environment

Same boxes, same vault, but in Europa-like environment

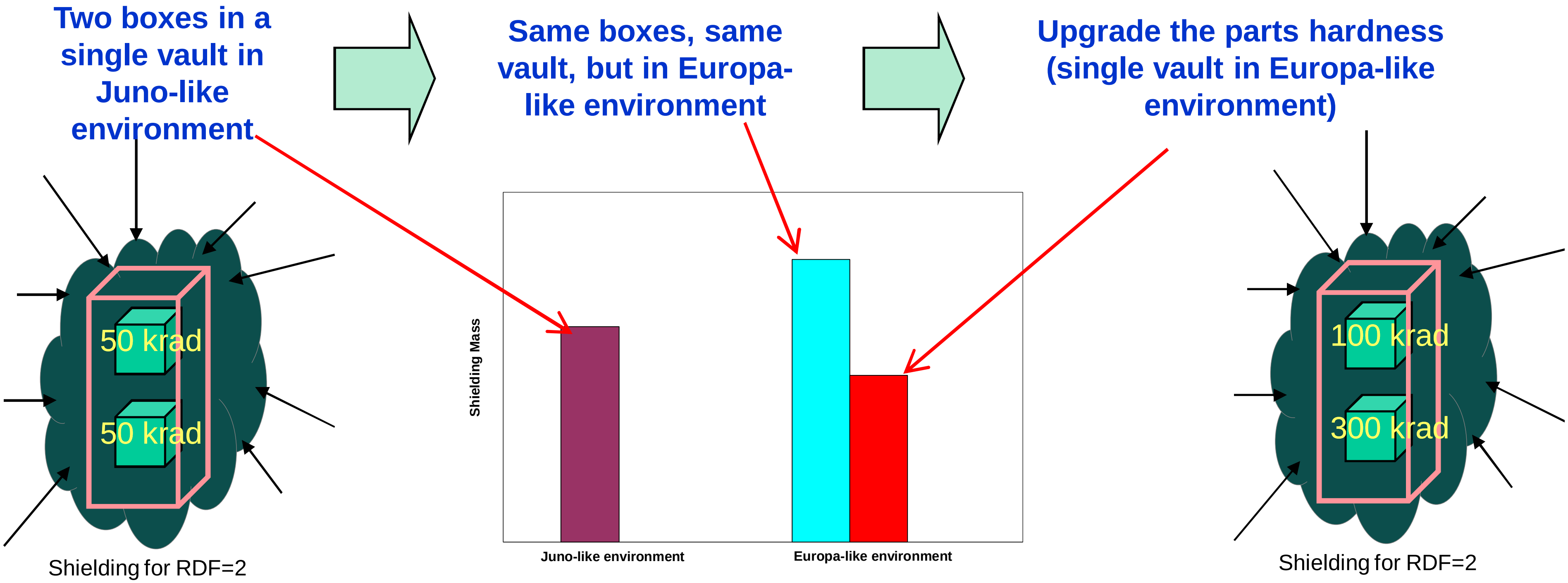


Shielding for RDF=2



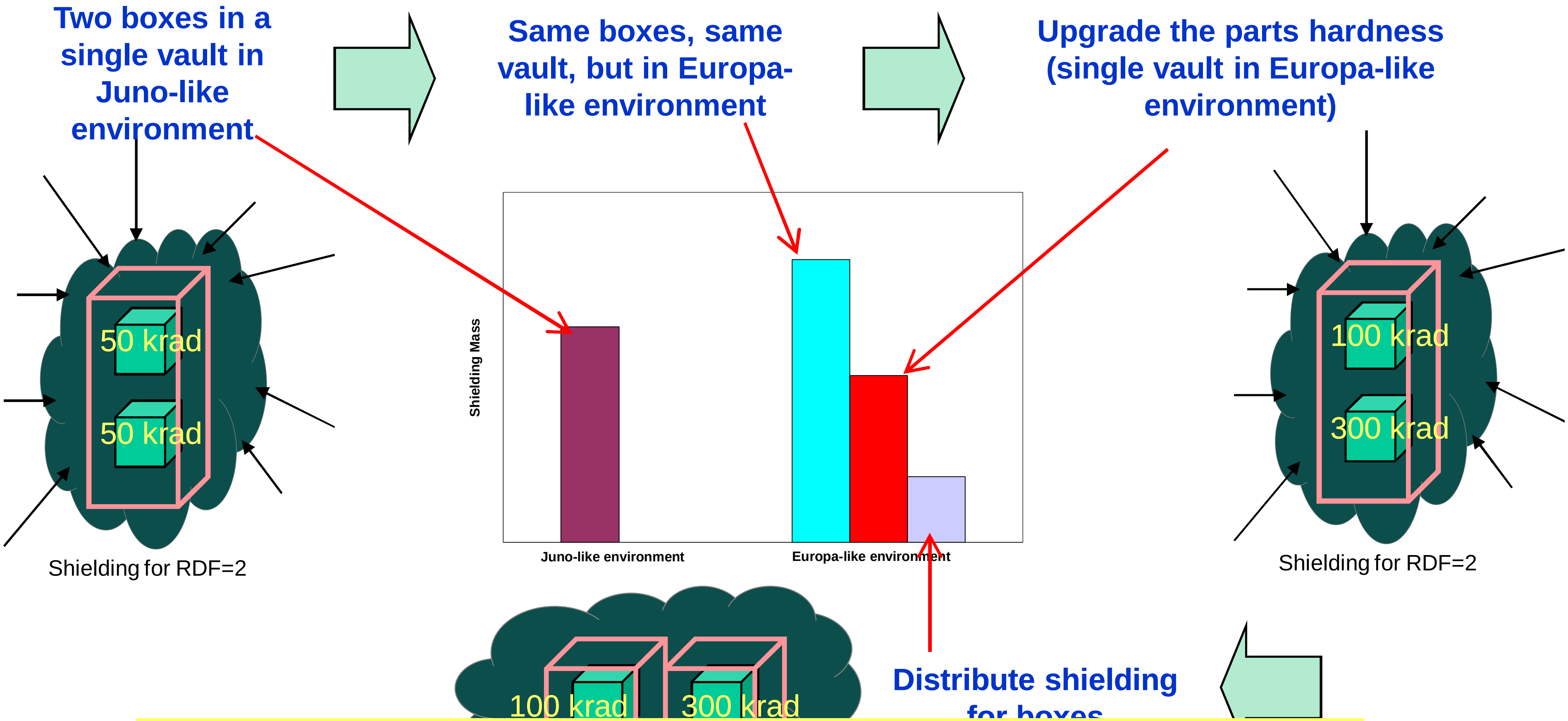
Shield Mass Comparison - A Simple Case Study

Scenario: Examine the trend of shielding mass changes for 2 electronics boxes in a Juno-like radiation environment vs. a EO-like environment



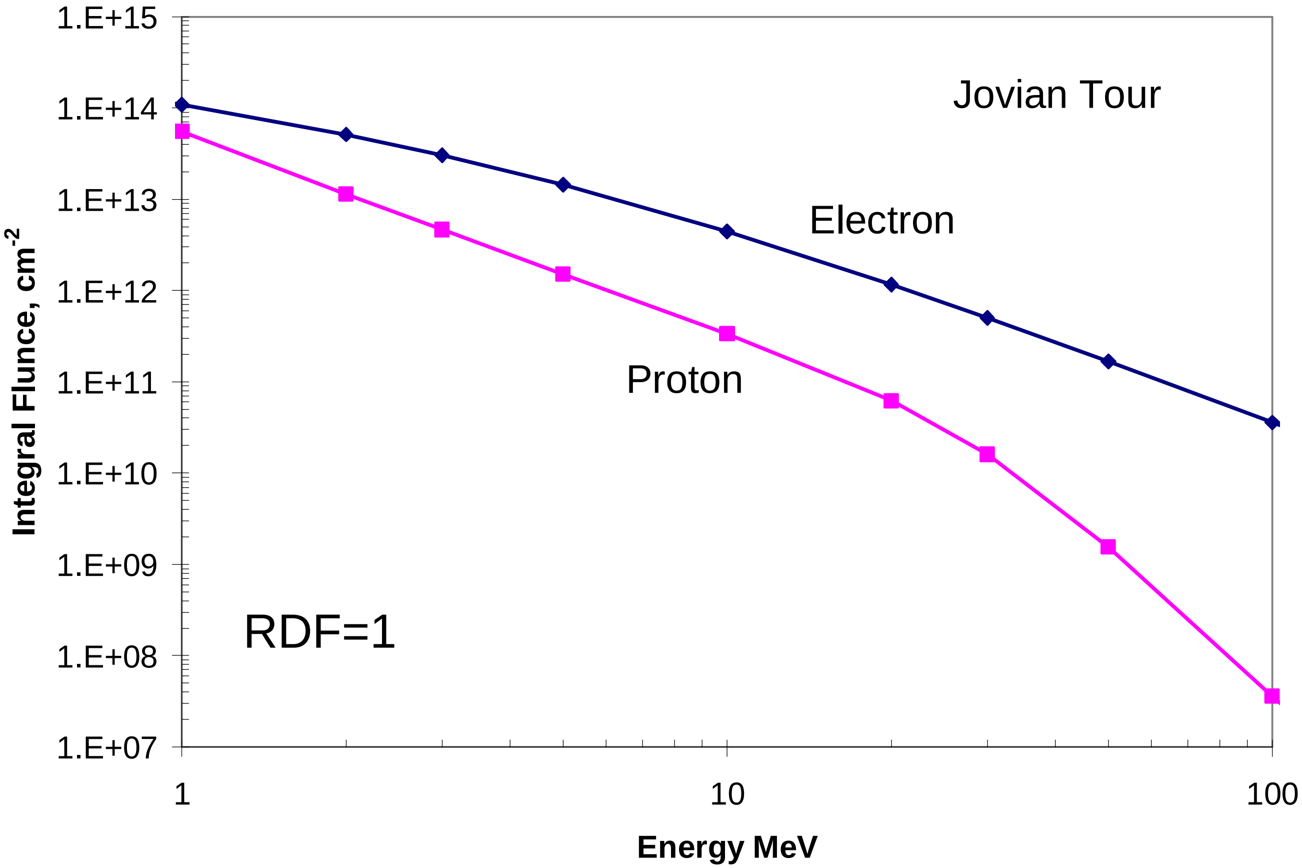
Shield Mass Comparison - A Simple Case Study

Scenario: Examine the trend of shielding mass changes for 2 electronics boxes in a Juno-like radiation environment vs. a EO-like environment



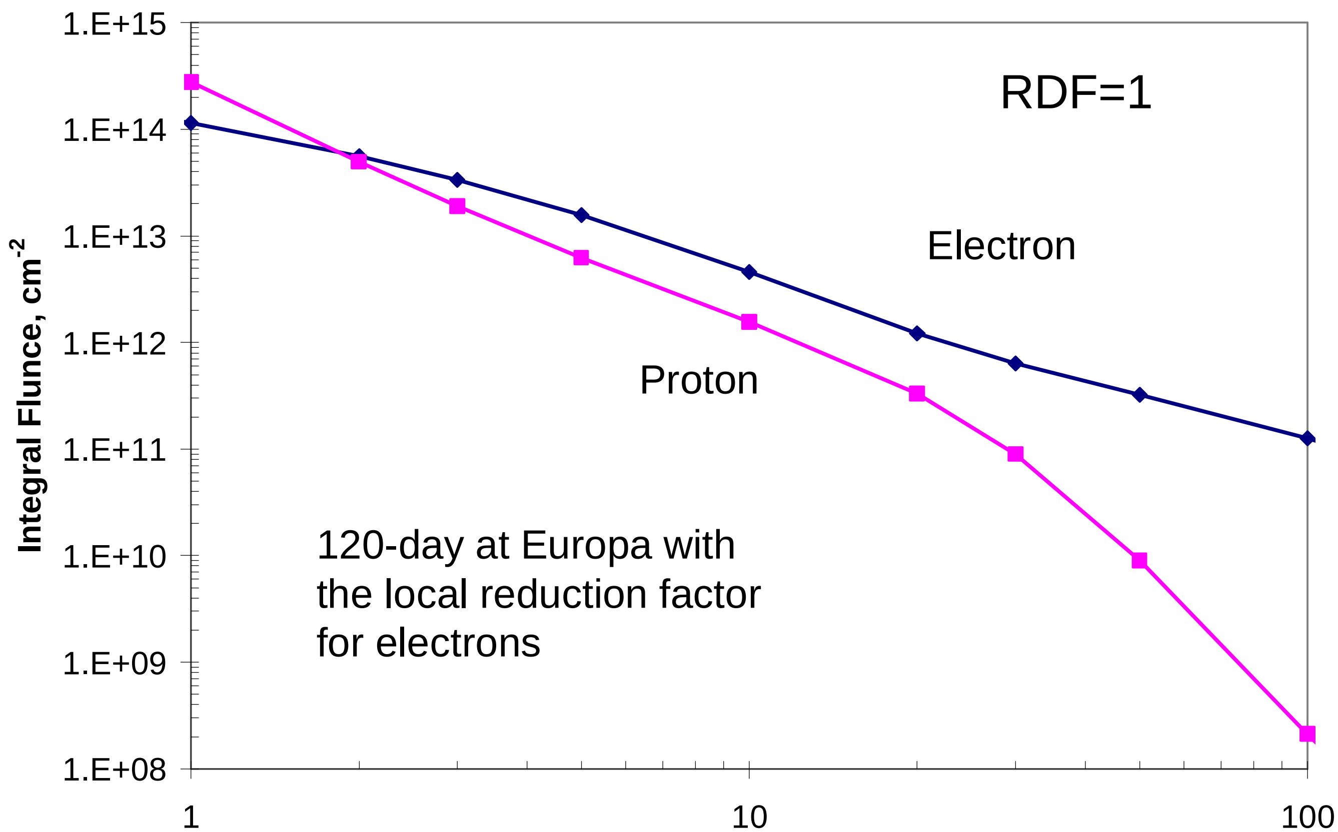
Distributed shielding minimizes shield mass for EE.

EE2007 Energy Spectra for the Jovian Tour



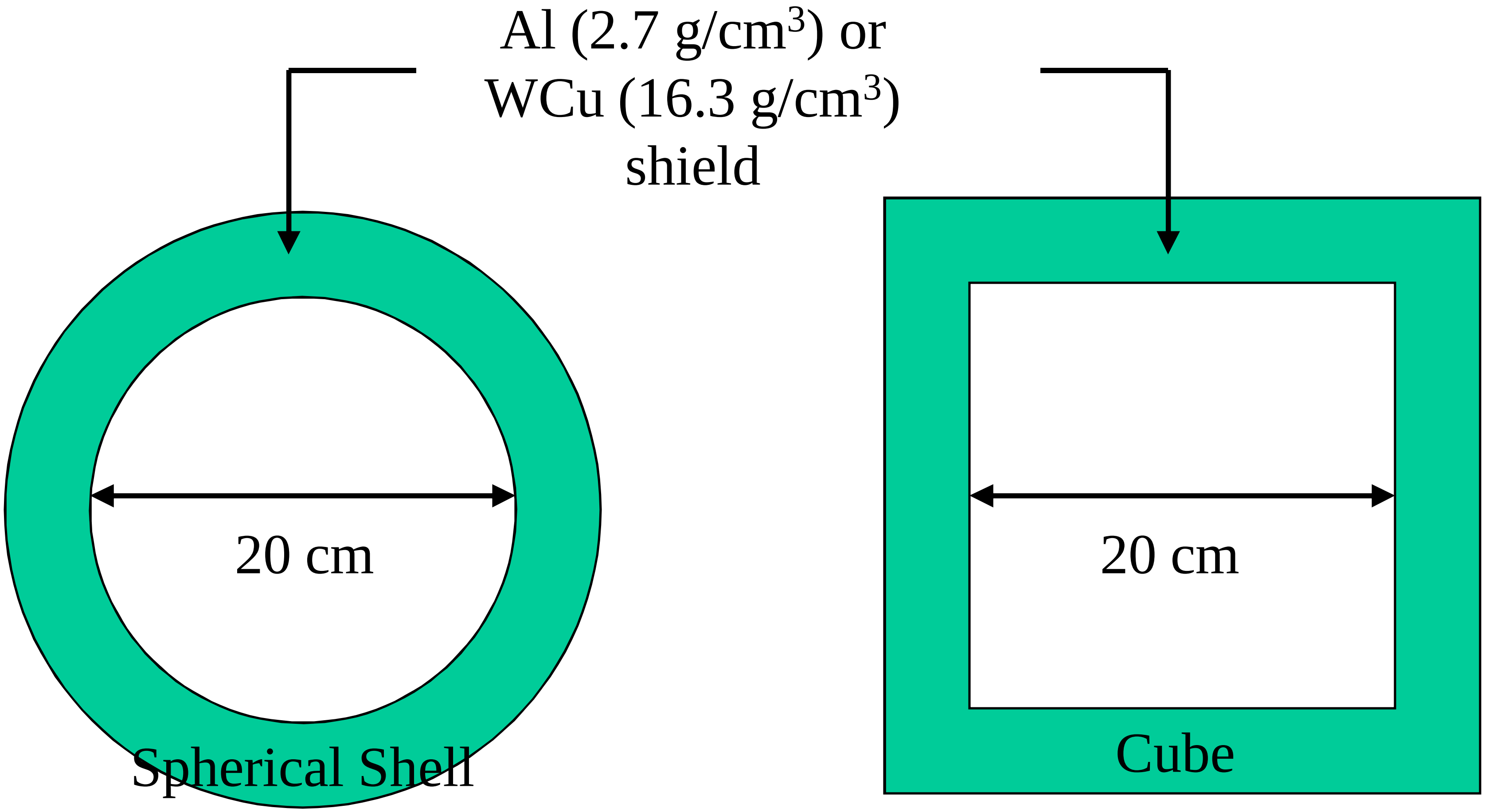
This figure shows the integral energy spectra of fluence during the jovian tour phase of the mission.

EE2007 Energy Spectra for 120-days at Europa



This figure shows the integral energy spectra of 120-day fluence at Europa

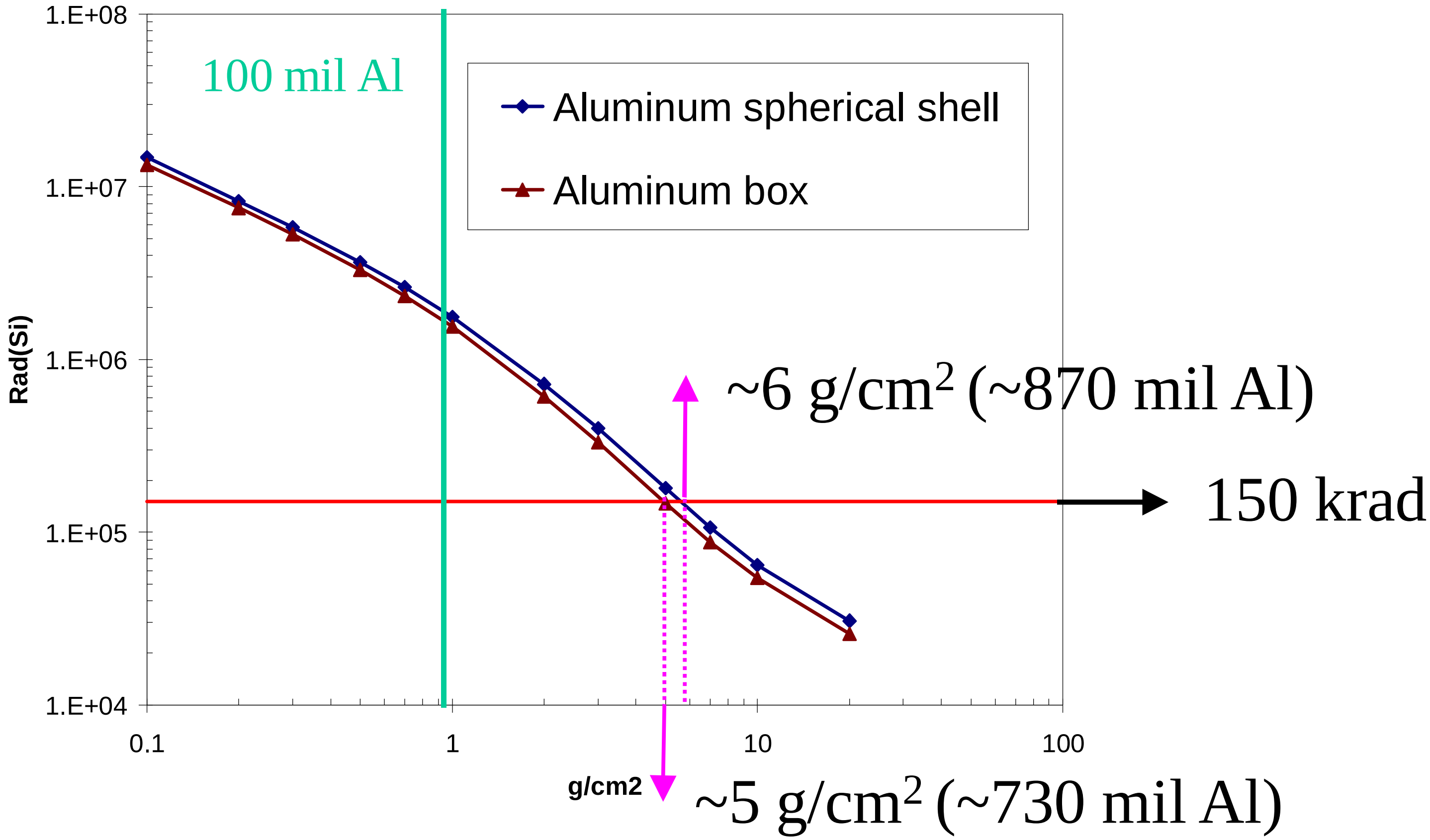
Geometry



Sample problem setup to examine the effects of shielding geometry and material. The external environments defined in the previous two charts are used for the calculations.

Europa Explorer TID vs. Shield Geometry

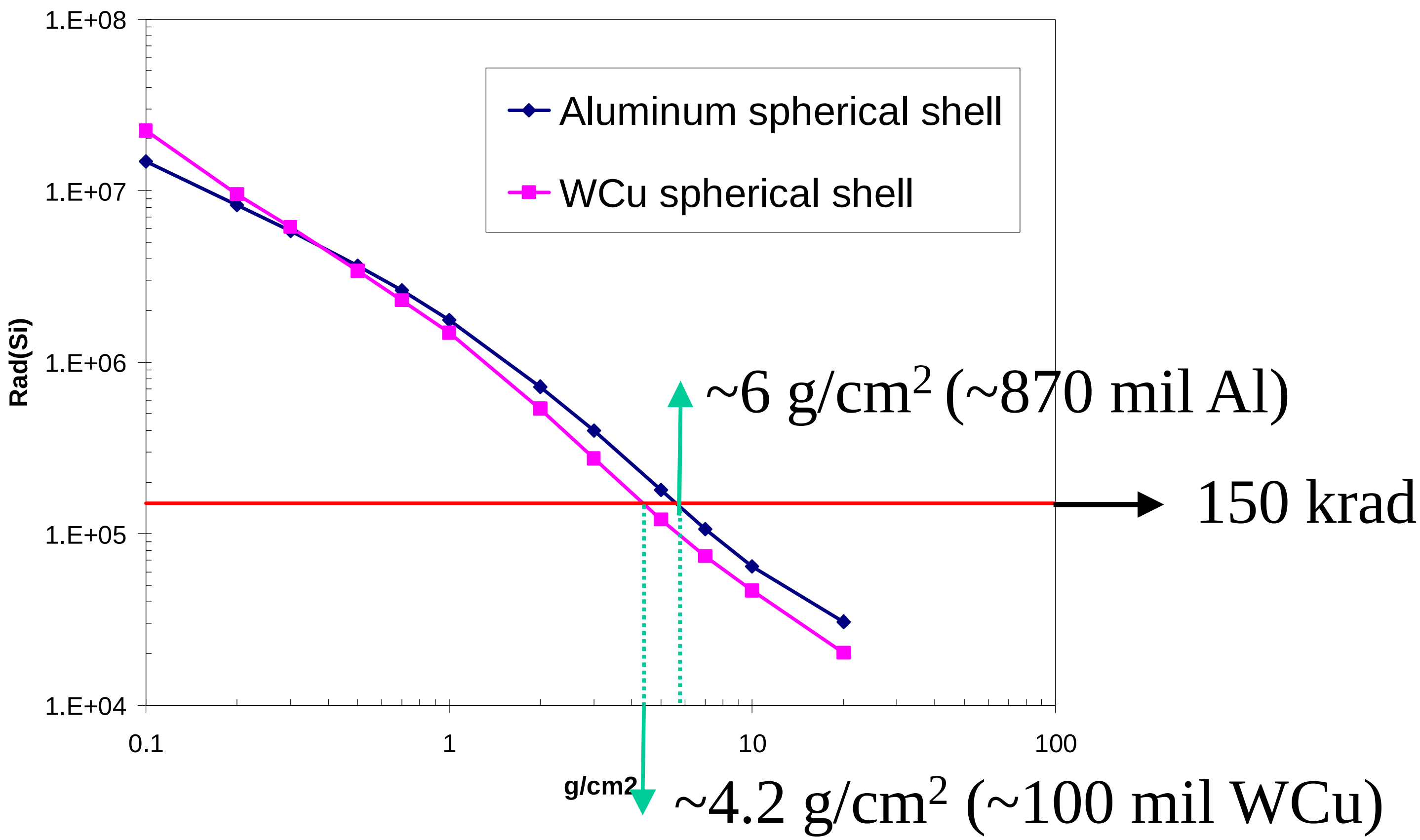
NOVICE



Spherical Shell vs. Box → Using a spherical shell dose depth curve may result in overestimate of the required the shielding thickness.

Europa Explorer TID vs. Shield Material

NOVICE

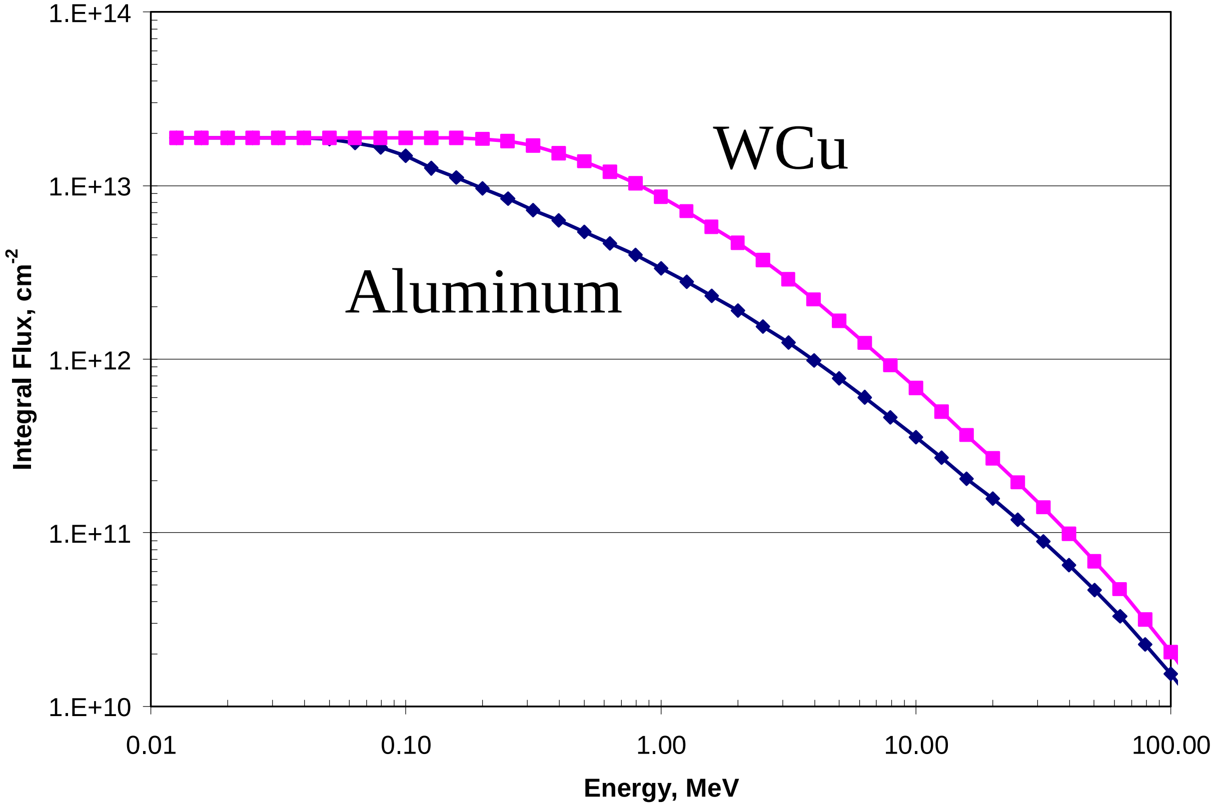


Aluminum vs. WCu → Using a high-Z material may save the required shielding mass.

Secondary Photon Spectrum

with 10 g/cm^2 spherical shell shielding

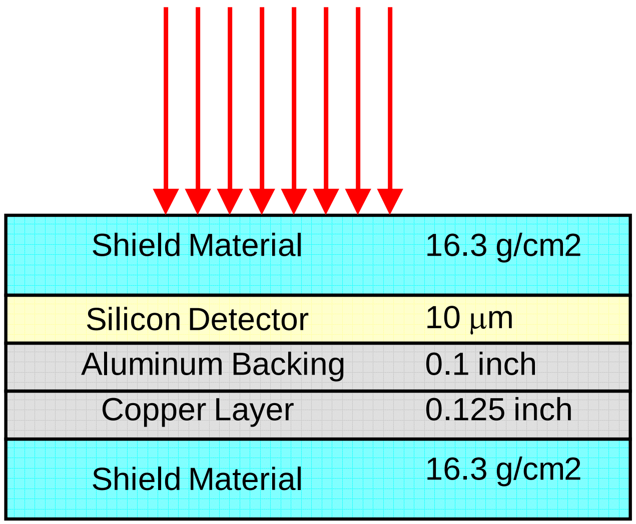
NOVICE



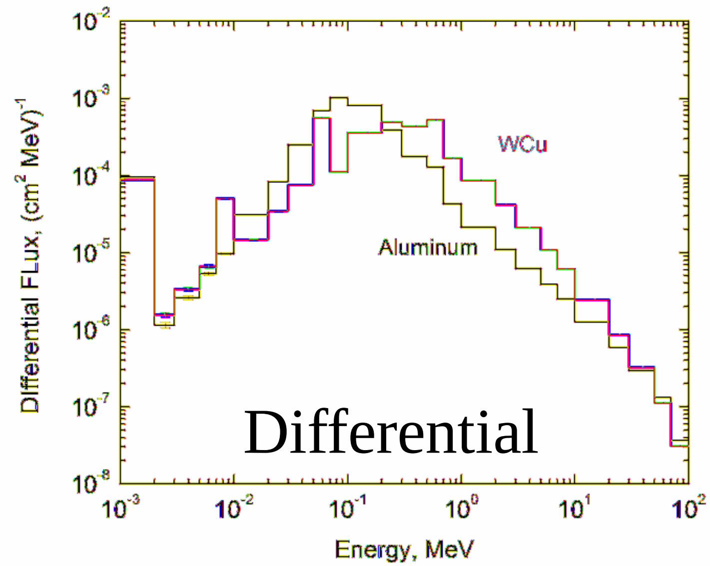
However, the use of high-Z material increases the secondary particle environment.

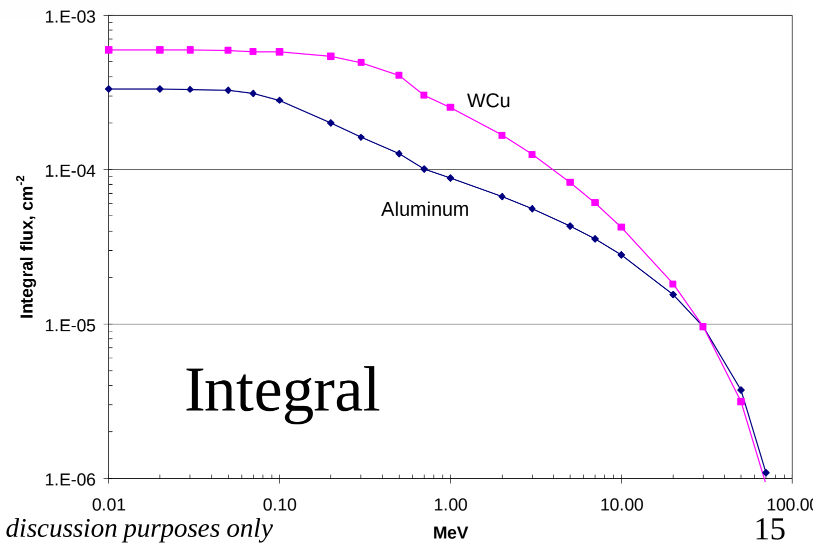
Other Test Case: Realistic Sensor Geometry (1-D)

100 MeV Electron Broad Beam



MCNPX simulation



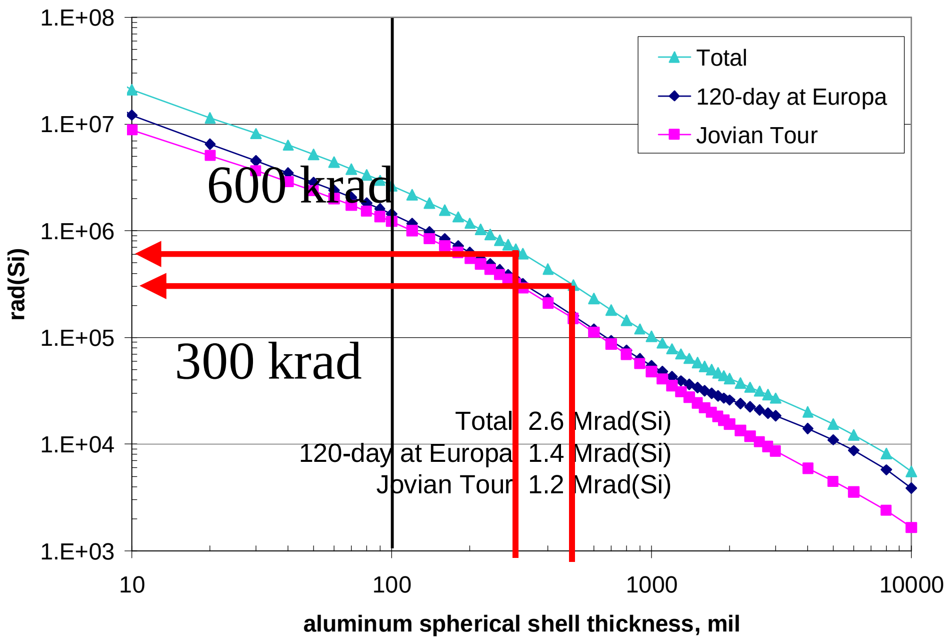


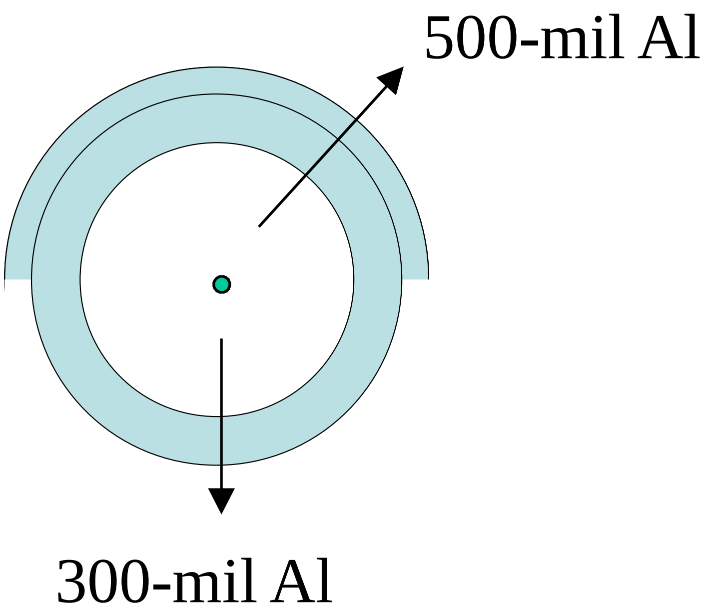
This example also illustrates the increase of secondary photon environment behind a high-Z shielding material.

Overview of Shielding Design Tools: Radiation Transport Codes

Ray Tracing or Geometry Sectoring

- Use of dose-depth curve to estimate the dose.





$$TID = 0.5*600 + 0.5*300$$
$$= 450 \text{ krad}$$

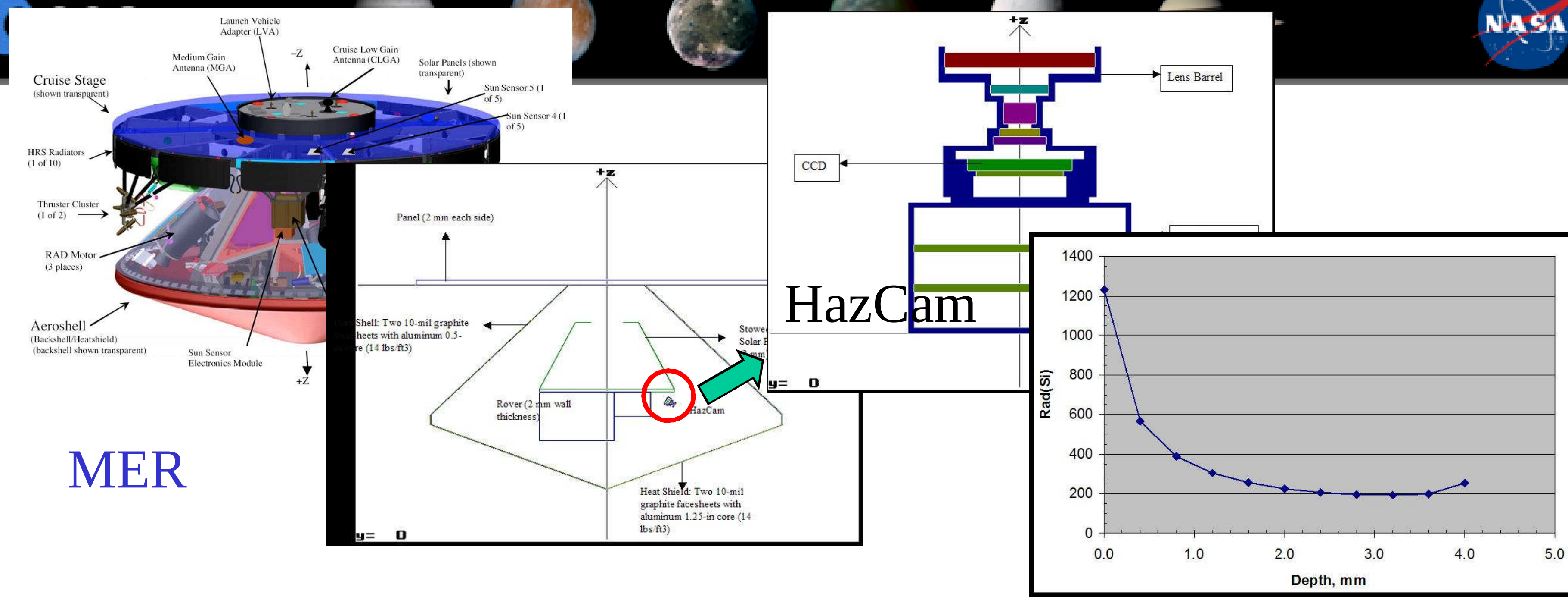
Monte Carlo Methods

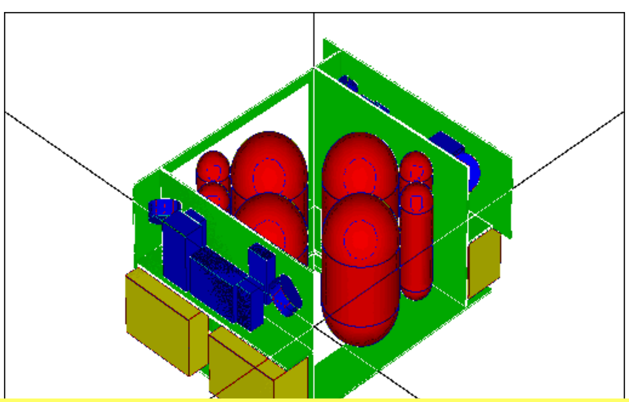
- Forward vs. Adjoint methods
  - Forward: follows particles from source to target
  - Adjoint: follows particles from target to source
- When are <u>forward</u> calculations more efficient?
  - When we require a large number of responses across the problem geometry from a source confined in relatively small volume
- When are <u>adjoint</u> calculations more efficient?
  - When we require responses over the small volume from a source distributed over large volume or surface

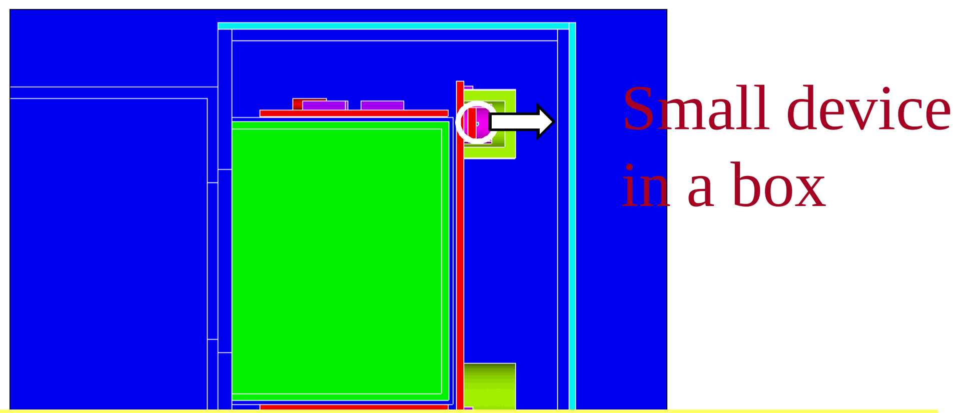
→ space radiation and spacecraft shielding

NOVICE

- Monte Carlo (adjoint)
  - Specifically developed for space applications
  - Only adjoint code available for charged particle transport as of now
- 3-Dimension
- Primary applications at JPL
  - Component level analysis with full spacecraft geometry
  - Routine TID and DDD calculations
- Particles:
  - Electrons, protons, photons, heavy Ions
- Pros:
  - Fast
  - Versatile geometry, relatively easy to use
- Cons:
  - Can not handle neutrons, secondary particles
  - Black box (poor user manual)







NOVICE is very effective to compute the radiation responses even in the complex geometry and has been used in almost all JPL flight projects.

Other Radiation Shielding Tools Available

	MCNPX	Geant4	FLUKA	MARS	PHITS
Version	2.6.0	9.1	2006 3b	15	
Affiliations	LANL	CERN IN2P3 INFN KEK SLAC TRIUMF ESA	CERN INFN	FNAL	JAEA RIST GSI Chalmers Univ.
Website	mcnpx.lanl.gov	www.geant4.org	pcfluka.mi.infn.it	www-ap.fnal.gov/MARS/	Upon request
Cost	Free	Free	Free	Free	Free

There are other tools available, not mentioned here.

Summary

- The radiation environment is a major challenge for instrument designers for Europa Orbiter.
  - Mission accumulated radiation effects (TID, DDD)
  - Increase of radiation-induced noise level
- Early addressing of radiation issues in design can mitigate impacts of significant radiation challenge.
- Extensive simulation and testing is highly recommended in the early phase of instrument development.
  - Many tools are available for detector simulation, but it requires some level of experience.
- The shielding design has to be looked at from the system level to maximize the resources available.

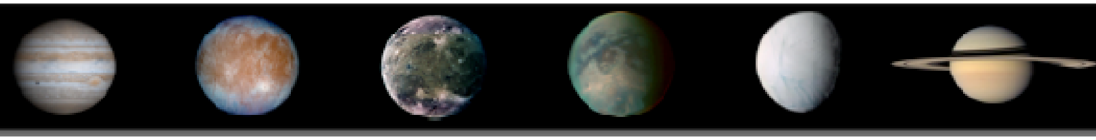
Backup:

Overview of Representative Radiation Transport Codes

Other Monte Carlo Codes

General	MCNPX	GEANT4	FLUKA	MARS	PHITS
Version	2.6.0	9.1	2006 3b	15	2.09
Lab. Affiliation	LANL	CERN IN2P3 INFN KEK SLAC TRIUMF ESA	CERN INFN	FNAL	JAEA RIST GSI Chalmers Univ.
Language	Fortran 90/C	C++	Fortran 77	Fortran 95/C	Fortran 77
Cost	Free	Free	Free	Free	Free
Release Format	Source & binary	Source & binary	Source & binary	Binary	Source & binary
User Manual	470 pages	280 pages	387 pages	150 pages	176 pages
Users	2500	~2000	~1000	220	220
Web Site	mcnpx.lanl.gov	Geant4.org	www.fluka.org	www-ap.fnal.gov/MARS	Upon request
Workshops	~7/year	~4/year	~1/year	~2/year	~1/year
Input Format	Free	C++ main Fixed geometry	Fixed or free	Free	Free
Input Cards	~120	N/A	~85	~100	~100
Parallel Execution	Yes	Yes	Yes	Yes	Yes

Courtesy G. McKinney of LANL



Geometry	MCNPX	GEANT4	FLUKA	MARS	PHITS
Description	MCNP-based	STEP Solids (Boolean CSG)	MORSE-based	Solids MCNP-based User defined	MCNP-based MORSE-based
Extensions Twisted Nested Repeated Voxel	 No Yes (universes) Yes Lattice (rec, hex)	 Yes Yes (logical vol.) Yes Yes (rec, cyl)	 No No Yes Yes	 No Yes Yes Yes	 No Yes (universes) Yes Lattice (rec, hex)
Reflections	3 types	Yes	Yes	Yes	Neutron albedo
Viewer **Debugger**	Built-in: 2-D Interactive X-Windows External: Vised Moritz	Built-in: 3-D Interactive OpenGL OpenInventor RayTracer External: WIRED VRML DAWN	Built-in: None External: Custom (X11) Others?	Built-in: 2-D Interactive Tcl/Tl 3-D Interactive OpenGL External: Custom	Built-in: 2,3-D Command PS via Angel External: Angel PS
Setup GUI	Vised Moritz	GGE	No	Tcl/Tl	No
CAD	STEP via GUI	STEP	No	No	No
Fields (E/B)	Yes in 2.6.0 (?)	Yes	Yes	Yes	Yes
Moving	Yes in 2.6.0 (?)	Yes	Yes	No	Yes

Courtesy G. McKinney of LANL

Source	MCNPX	GEANT4	FLUKA	MARS	PHITS
Fixed					
General					
Explicit	Yes	Yes	Yes	Yes	Yes
Distribution	Yes	Yes	No	Yes	Yes
Dep. Dist.	Yes	GPS	No	Yes	Yes
External	SSW/SSR	Yes	No	Yes	Yes
User Sub.	Yes	Yes	Yes	Yes	Yes
Eigenvalue	Yes	No	No	No	No
Burnup	Yes	No	No	No	No

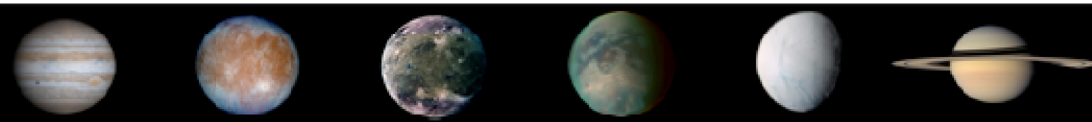
Courtesy G. McKinney of LANL

Physics	MCNPX	GEANT4	FLUKA	MARS	PHITS
Particles	34	68	68	41	38
Charged particles Energy loss Scatter Straggling XTR/Cherenkov	CSDA Bethe-Bloch Rossi Vavilov No	CSDA Bethe-Bloch Lewis Urban Yes	CSDA Bethe-Bloch Moliere Custom No/yes	CSDA Bethe-Bloch Moliere* Custom No	CSDA Bethe-Bloch Moliere Vavilov No
Baryons Neutron Low High Proton Low High Other	 Cont. (ENDF) Models Cont. (ENDF) Models Model List: Bertini ISABEL CEM INCL FLUKA89>3 GeV LAQGSM	 Cont. (ENDF) Models Models Models Model list: Hadron-nucleous GHEISHA INUCL(Bertini) BIC CHIPS QGS/FTF>8 GeV	 Multigroup(72) Models Models Models Model list: PEANUT(GINC) DPM+Glauber > 5 GeV	 Cont. (ENDF) Models Models Models Model list: Custom CEM LAQGSM DPMJET	 Cont. (ENDF) Models Models Models Model list: Bertini JAM>3 GeV
Leptons Electrons Muon Neutrino Other	 ITS 3.0 CSDA/decay Production Decay	 EEDL, EADL Models Production Decay	 Custom Models Models Decay	 Custom Models Models Models	 ITS 3.0 CSDA/decay Models Models

Courtesy G. McKinney of LANL

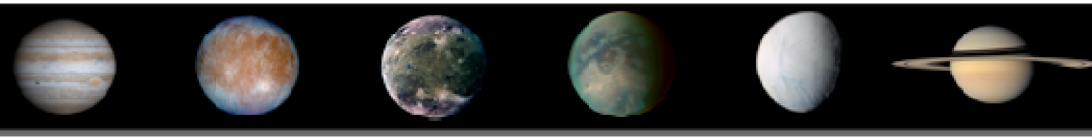
Physics	MCNPX	GEANT4	FLUKA	MARS	PHITS
Mesons	Models	Models	Models	Models	Models
Photons Optical x-ray/γ Photonuclear	 No ITS 3.0 Libraries (IAEA) CEM	 Yes EPDL97, EADL CHIPS	 Yes Custom+EPDL97 PEANUT VMDM	 No Custom Custom CEM	 No ITS 3.0 No
Ions	ISABEL LAQGSM	AAM EDM BLIC	RQMD-2.4 DPMJET-3	LAQGSM	JQMD JAMQMD > 3 GeV/u
Delayed	n,γ	α,β,γ	β,γ	γ	n

Courtesy G. McKinney of LANL



Tallies	MCNPX	GEANT4	FLUKA	MARS	PHITS
Standard					
Flux					
Volume	Yes	Yes	Yes	Yes	Yes
Surface	Yes	Limited	Yes	Yes	Yes
Point/ring	Yes	No	No	Yes (neutrons)	No
Current	Yes	Limited	Yes	Yes	Yes
Charge	Yes	Yes	Yes	Yes	Yes
Kinetic energy	Yes	Yes	Yes	Yes	Yes
Particle density	Yes	Yes	No	No	No
Reaction rates	Yes	No	Star (inelastic)	Yes	Yes
Energy deposition	Yes	Yes	Yes	Yes	Yes
Rapidity	No	Yes	Yes	Yes.	No
DPA	HTAPE3X	??	Some	Yes	Yes
Momentum	No	Yes	Yes	Yes	No
Pulse-height	Yes	User input	Yes	No	Yes
Termination	Partial	??	Yes	Partial	Yes
Modifiers	9	2	2	2	2
Special					
Mesh	rec, cyl, sph	rec, cyl	rec, cyl	rec, cyl, sph	rec,cyl
Coincidence	Yes	No	Yes	Yes	Yes
Residuals	Yes	No	Yes	Yes	Yes
Activation	Yes	??	Yes	Yes	No
Event logs	Yes	Yes	Yes	Yes	Yes
Convergence Tests	10	Error	Error	Error	Error

Courtesy G. McKinney of LANL



Tallies	MCNPX	GEANT4	FLUKA	MARS	PHITS
Viewer	Built-in: 1-D, 2-D Custom X-Windows External: IDL Tecplot GNUplot PAW	Built-in: No External: JAS PI Open Scientist	Built-in: None External: Custom (X11) GNUplot PAW ROOT	Built-in: Custom External: PAW	Built-in: Angel External: Angel
Variance Reduction					
Population control Region biasing Weight cutoff Weight window mesh Energy biasing	 Yes Yes Yes Yes	 Yes Yes Yes No	 Yes Yes Yes Yes	 Yes Yes Yes Yes	 Yes Yes Yes Yes
Modified sampling Source biasing Implicit capture Exp. transform Production biasing Angular bias	 Yes Yes Yes Yes Via DXTRAN	 RDM Yes No Yes ??	 Yes Yes Yes Yes Yes	 Yes Yes Yes Yes Yes	 Yes Yes No Yes Yes
DXTRAN	Yes	No	No	No	No
Viewer	2-D contour	No	No	No	No

Courtesy G. McKinney of LANL